Discussion PWA

[Mokeev, Doering]

- Spontaneous discussion
- Questions of interest for PWA:

1) Contributed questions:
   - ANL/Osaka web site: https://www.phy.anl.gov/theory/research/anl-osaka-pwa/. [T.S.H. Lee]
   - Roper-like Resonances – Why interesting? [A. Hosaka]
   - More on experiments at J-Parc (pions, kaons) [T. Ishikawa]
   - Pentaquarks at J-PARC [H. Nuomi]
   - Phenomenological amplitude parametrization [G. Ramalho]
2) How helpful can the combined amplitude analyses of exclusive meson photo- and electroproduction data be in providing evidence for new N* states that exist in Nature but are not included into the amplitudes used to fit the data, in particular, to help interpret the data at W>1.8 GeV in identifying hybrid baryons and “missing” resonances?
3) Methods: Opportunities for the global multi-channel analyses to determine N* electroexcitation amplitudes from $N\pi$, $N\eta$, $K\Lambda$, $K\Sigma$, $\pi^+\pi^-p$ electroproduction data a) at $Q^2<5.0$ GeV^2 (available from CLAS), b) at $Q^2<10$ GeV^2 (expected from CLAS12) analyzed combined with the relevant data on the photo- and hadroproduction of the final states mentioned above. What is the importance of spin observables and how can they increase the capabilities of such approaches to constrain the resonance vs. non-resonant contributions.
4) Methods: How to connect the Amplitudes Analysis from the pion-induced sector to that of the electromagnetic (electron/photon beams) sector (especially 2-pion production)
5) Data: Which data on exclusive meson hadroproduction with meson beams can be obtained within 5-10 years and expected impact from these data on extraction of resonance electroexcitation amplitudes from global multichannel analyses described in 3)?
6) Data: Will density matrix elements be of use as they form constraints on the bilinear combinations for the helicity amplitudes?

Discussion PWA – contd.

7)

Method: Urgent need for the development of the reaction model(s) capable of determining $\gamma_v pN^*$ electrocouplings from the exclusive $K\Lambda$ and $K\Sigma$ electroproduction channels needed as an important part of theory support for the experimentalists efforts to search for new states of the baryon matter.

8)

Methods: Can the AA-PWA framework developed for nearly model-independent determination of the pseudo-scalar meson-baryon photoproduction amplitudes be extended to determine the amplitudes of the pseudo-scalar meson-baryon electroproduction channels? [Y. Wunderlich]

9)

The prospects to determine electroexcitation amplitudes for nucleon resonances excited off free neutrons at rest from the data on $\pi^- p$ differential cross sections off neutrons bound in deuterons at W<1.8 GeV and at Q^2<1.0 GeV^2.

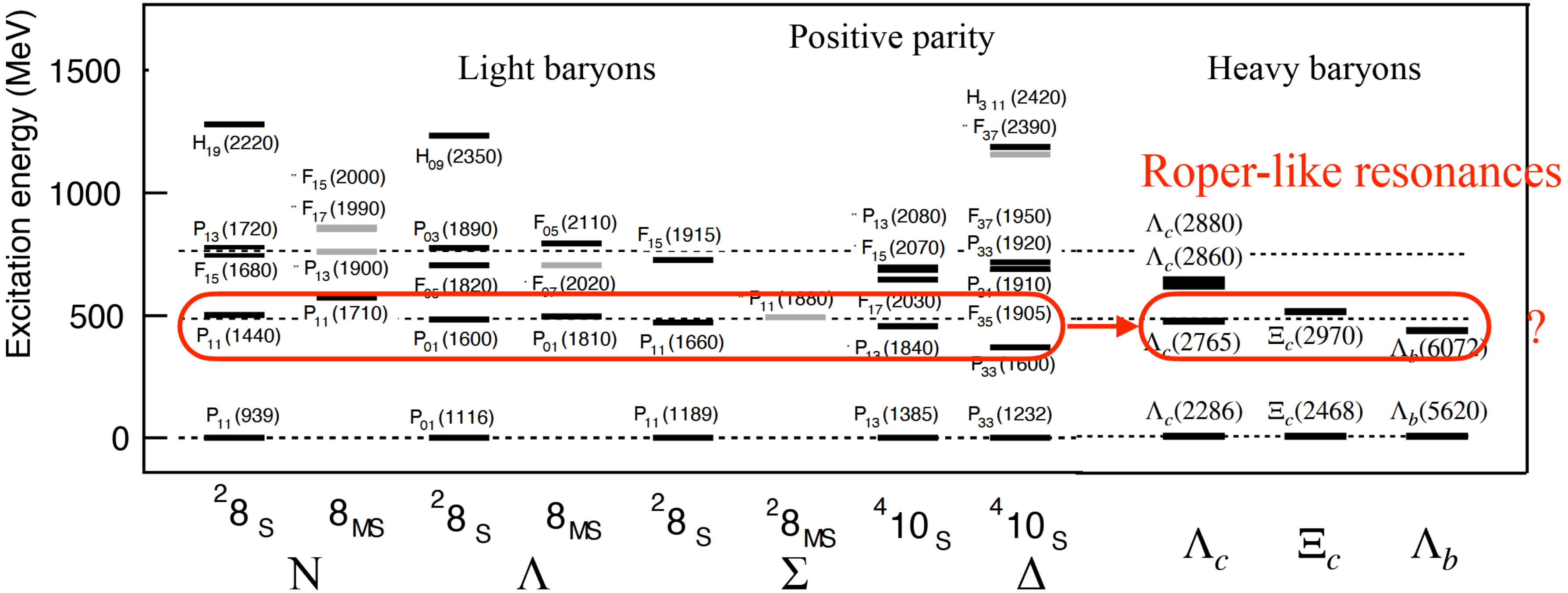
10)

Data base issues:

- Uncertainties dominated by consistency issues of different measurements
- How to deal with inconsistent data? Data pruning? Older vs. newer data.
- Energy/Q2-dependent analyses never achieve a good chi2 - can we ever get to the point of assigning a significance to a resonance (e.g., 3-sigma)?

Roper like resonances — why interesting?

Atsushi Hosaka, RCNP, Osaka and ASRC, JAEA



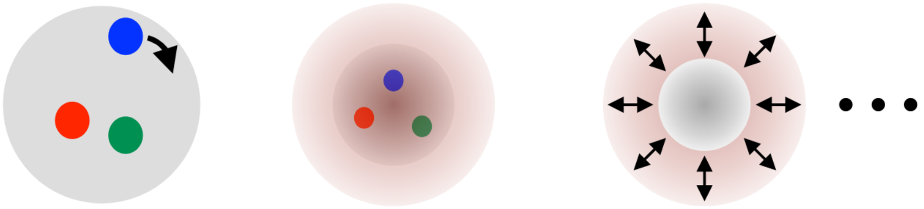
Takayama et al, PTP. 101 (1999) 1271; Arifi et al, PRD 101 (2020) 11, 111502; 103 (2021) 9, 094003
"Hadrons from quarks and chiral symmetry", To appear in Handbook of Nuclear Physics (Springer)

- Mass excesses are ~ 500 MeV independent of flavors
- Decay widths are large as compare to the naive NR predictions
- $A_{1/2}(N^*)$, Q^2 dependence with the sign at the photon point

Questions to be answered

Structure

Single particle, meson cloud, collective



Quark Hybrid Skyrmion Holographic

Kubota-Ohta, PLB65, 374 (1976)

spin-orbit interaction is missing in the latter. FKR apply the Bargmann–Wigner condition which brings about terms proportional to $\boldsymbol{\sigma}^{(i)} \times \boldsymbol{P}_1$ and $\boldsymbol{\sigma}^{(i)} \times \boldsymbol{P}_2$

....

function. Thus the Bargmann–Wigner equation amounts to a neglect of the spin-orbit interaction which comes from small components of the quark Dirac spinors, namely to a neglect of the effect of the quark internal motion, for the quarks inside the resonance must be at rest in its rest frame. Le Yaouanc et al. [9] also indicate

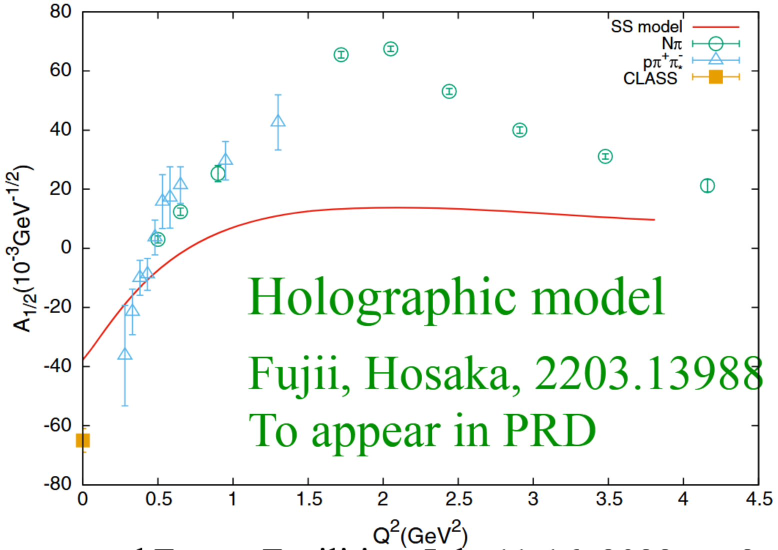
Feynman, Kislinger, Ravndal, PRD3 (1971) 2706

One pion decays

State	NR	RC	Data Pole/BW
$N(1440)$	13	164	175/350
$\Lambda(1600)$	20	112	180/200
$\Sigma(1660)$	7	84	$290^{+140}_{-40}/\approx 200$

Arifi et al, PRD 105 (2022) 9, 094006

EM transition $A_{1/2}$



Virtual pions (kaons)?

virtual pions produced in $(\pi^{\pm}, \rho^0)$ at $5 \sim 20$ GeV/c

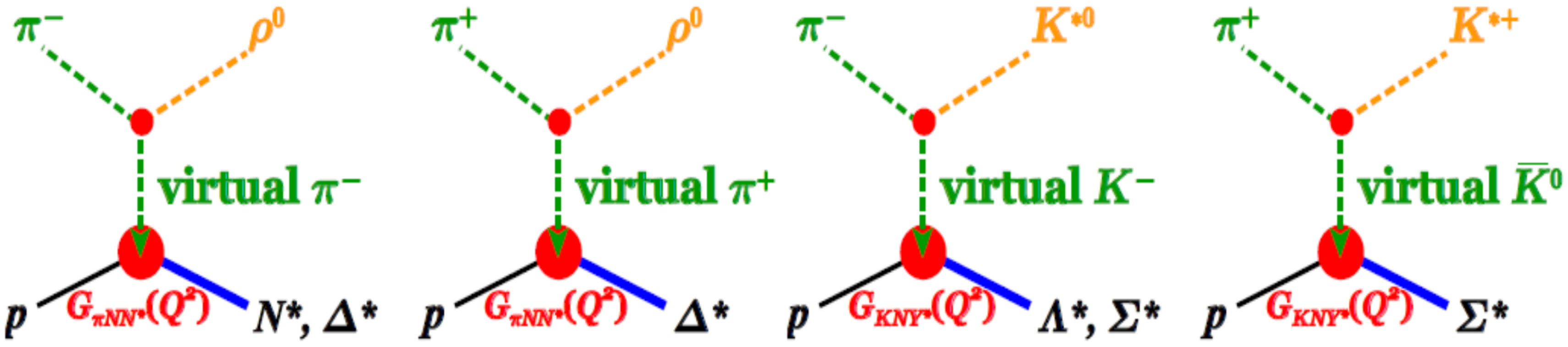
t channel contributions are dominant for this reaction when ρ^0 mesons are detected at forward angles.

Additionally dominant exchange particle must be pions.

Does this work for extracting the axial vector form factor for resonances?

virtual kaons produced in $(\pi^{\pm}, K^{*0})$ at $5 \sim 20$ GeV/c

a similar question but in this case mass ratio between K and K^* is much smaller than that between π and ρ.



Planned experiments at J-ARC (FYI)

$\pi^- p \to \phi n$ at $P_\pi = 1.6, 1.8, 2.0, 2.2,$ and $2.4\ \mathrm{GeV}/c$

using the J-PARC E16 spectrometer (the proposal submitted)

Takatsugu Ishikawa, Atsushi Hosaka, Sang-Ho Kim, Hiroyuki Noumi, Hiroyuki Sako et al.

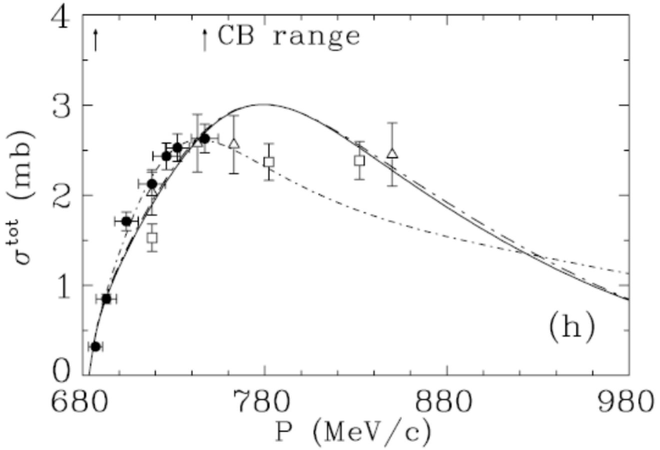
a different channel to clarify the following items

1. $\gamma p \to \phi p$ shows an unidentified bump at $W = 2.2$ GeV in $d\sigma/dt\ _{t=-|t|_{\min}}$
2. $\gamma p \to J/\psi p$ does not show any peaks corresponding to P_c
3. $\gamma p \to \phi p$ provides completely different scattering lengths from those determined in other methods.

$\pi^- p \to \eta n$ at $P_\pi < 1.1\ \mathrm{GeV}/c$

using the KEK-E246 CsI(Tl) calorimeter (in preparation)

the $\pi^- p \to \pi^0 \pi^0 n$ data will be included automatically



S. Parakhov et al., Measurement of $\pi^- p \to \eta n$ from threshld to $p_{\pi^-} = 747\ \mathrm{MeV}/c$, Phys. Rev. C 72, 015203 (2005).

Isospin partner of Pc's at the J-PARC high-momentum beam line:

Hiroyuki Nuomi

J-PARC can provide

$$\pi^- p \to "P_c^0" \to J/\psi n, \quad Y_c^{(*)} D^{(*)},$$

which may provide different information from those given by γ-induced reactions through s-channel formation process.

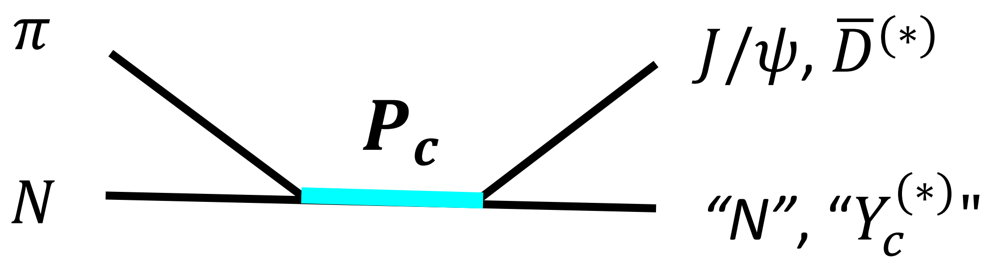
- Unknown information related to the cross section on
  - πN coupling to P_c
  - $\bar{c}c$ component in N^*
  - mixing ratio of $qqq\bar{c}c$ to qqq

  would be provided.
- branching ratio of $Y_c^{(*)} D^{(*)}$ to $J/\psi n$ may give us a hint if P_c is a molecular like state.

Hiroyuki Nuomi

P_c^0 at J-PARC

- P_c^0 : s-channel formation with 10-GeV/c π^- on p

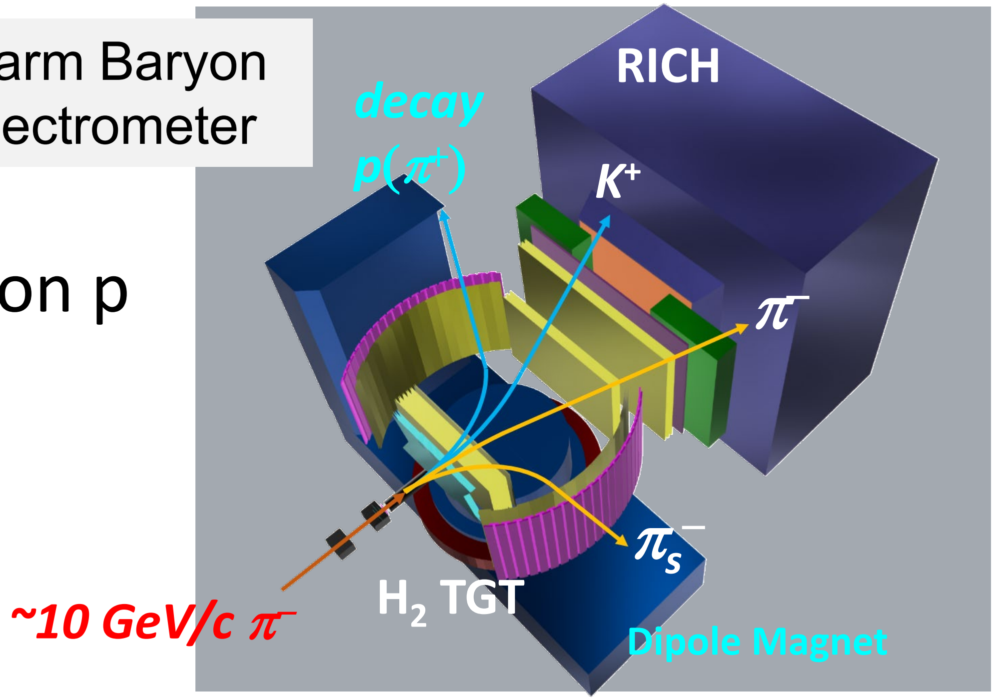


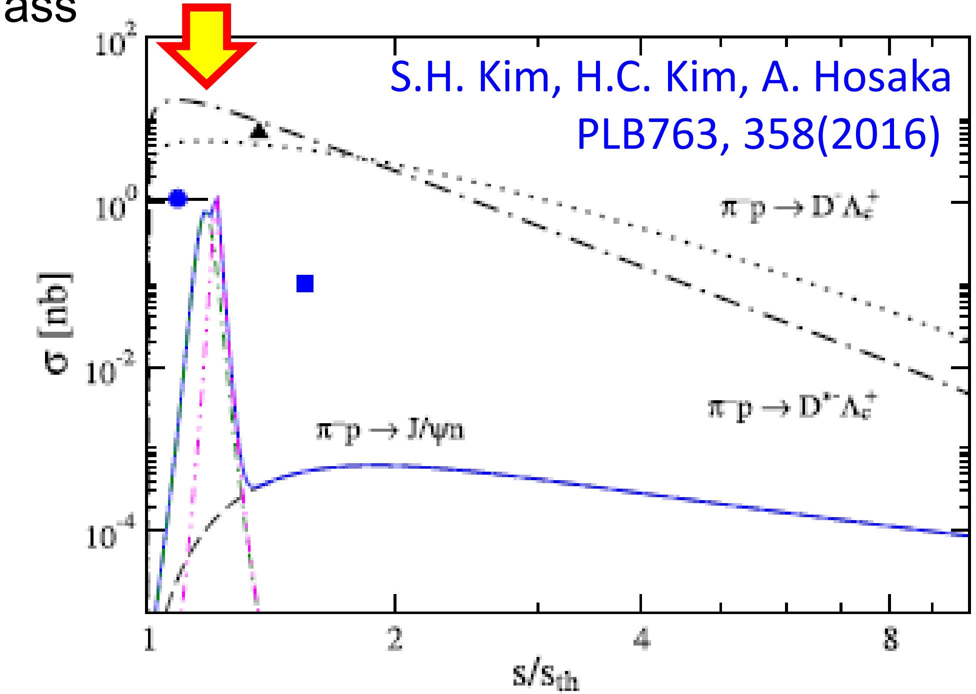
"ID as a Missing Mass"

$$\sigma_L = (2L+1)\frac{\pi}{k^2}\frac{\Gamma_{\pi N}\Gamma_{J/\psi p}}{(E-m)^2+\Gamma_{tot}^2/4}$$

- Cross Section: <1 nb?
  - $\Gamma_{\pi N}/\Gamma_{tot}$~ 10^{-5} ?
  - $\Gamma_{j/\psi p}/\Gamma_{tot}$~0.05 ?

Charm Baryon Spectrometer

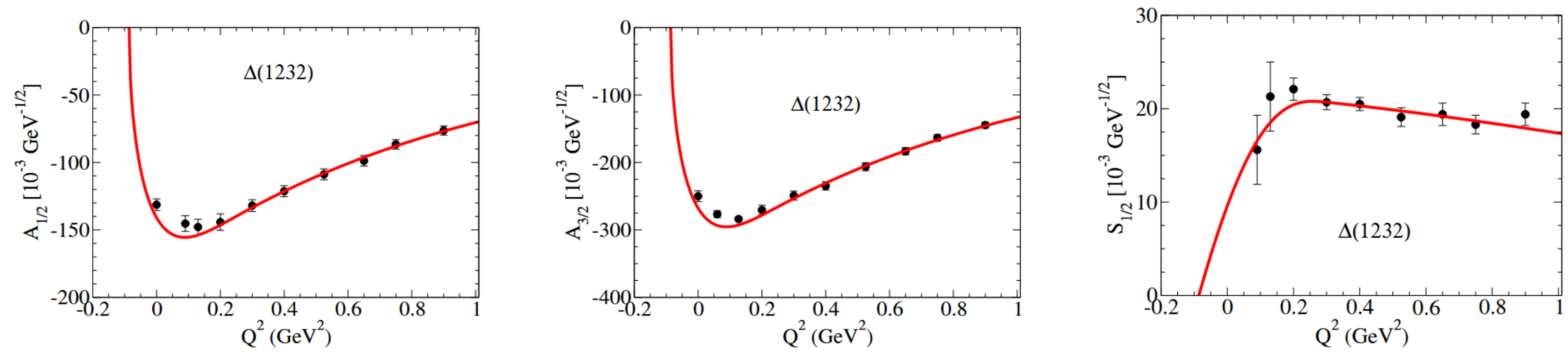




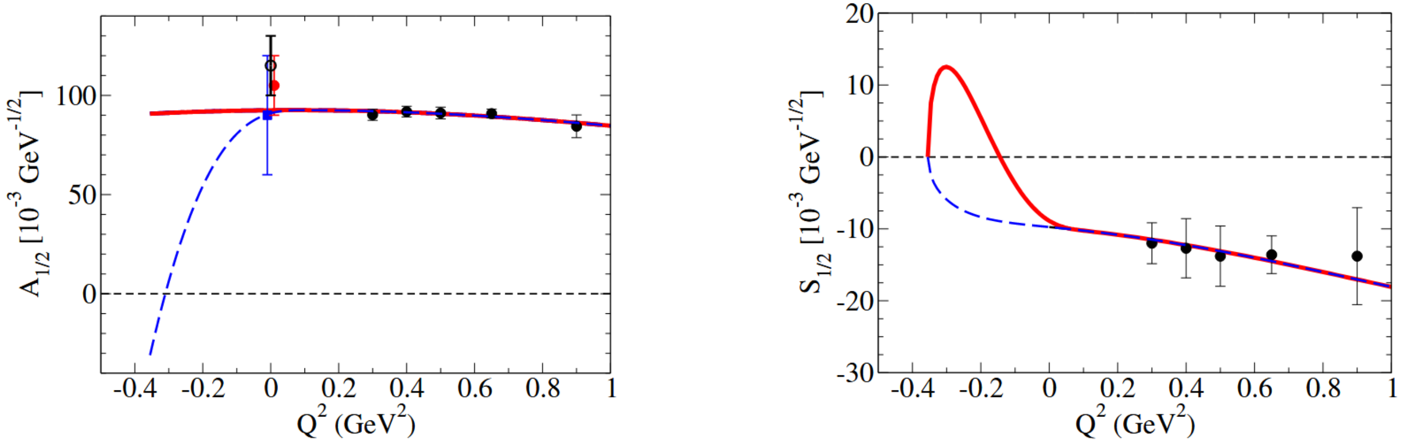
Comments on empirical parametrizations of the data

- The microscopic structure of the $\gamma^* N \to N^*$ current implies correlations between the amplitudes and constraints in the amplitudes
- Those constraints **cannot** be ignored in the empirical parametrizations of the amplitudes **at low-**Q^2 ($Q^2 < 0.3$ GeV^2): $\Delta(1232)$, $N(1535)$
- Best way to take into account those effects:
  use *proper* **form factors** $(F_1, F_2, ...)$ instead of **helicity amplitudes**
  – **automatic verification** of the pseudothreshold constraints
- **Alternative:**
  Consider analytic continuations of parametrizations for $Q^2 \leq Q_P^2$ compatible with the constraints at the pseudothreshold

Comments on empirical parametrizations of the data



$\Delta(1232)$: signature of the $|\mathbf{q}|$-dependence near the pseudothreshold very clear in the data



$N(1535)$: there are very different solutions compatible with the data

General AA-PWA approach

The *perfect (dream-) scenario* for the AA-PWA procedure, applied to any (2-body) reaction with $N_{\mathcal{A}}$ amplitudes, is the following: [A. Švarc, YW & L. Tiator, Phys. Rev. C **102**, 064609 (2020)]
[A. Švarc, YW & L. Tiator, Phys. Rev. C **105**, no.2, 024614 (2022)]

- Step I.) Amplitude analysis of experimental data, which comprise a complete dataset with perfect, uniform kinematic binning and phase-space coverage:
  - ∗) Moduli $|\mathcal{A}_1|, \ldots, |\mathcal{A}_{N_{\mathcal{A}}}|$ & relative phases $\phi_{ij}^{\mathcal{A}}$ of spin-amplitudes $\mathcal{A}_k$ (these may be transversity amplitudes) are extracted for each 'bin' in phase-space,
  - ∗) In practice: extract 'phase-constrained' set of amplitudes $\tilde{\mathcal{A}}_k$ ($\mathcal{A}_1 = |\mathcal{A}_1| > 0$),
  - ∗) Import unknown overall-phase $\phi(W, \theta)$ from energy-dependent (ED) model,
  - ∗) Generate the *penalizing amplitudes* $\mathcal{A}_k^{\text{pen.}} \equiv e^{i\phi} \tilde{\mathcal{A}}_k$,
- Step II.) Perform *penalized PWA* on the same dataset by minimizing $\Phi := \chi^2_{\text{data}}(W) + \mathcal{P}(W)$, where:

$$\chi^2_{\text{data}}(W) = \sum_{i=1}^{N_{\text{data}}} w^i \left[\mathcal{O}_i^{\text{exp.}}(W, \theta_i) - \mathcal{O}_i^{\text{theor.}} \left(\mathcal{M}_\ell^{\text{fit}}(W), \theta_i \right) \right]^2 ,$$

$$\mathcal{P}(W) = \lambda_{\text{pen.}} \sum_{i=1}^{N_{\text{data}}} \sum_{k=1}^{N_{\mathcal{A}}} \left| \mathcal{A}_k \left(\mathcal{M}_\ell^{\text{fit}}(W), \theta_i \right) - \mathcal{A}_k^{\text{pen.}}(W, \theta_i) \right|^2 ,$$

In practice, the non-completeness of the analyzed database forces one to do:

- Step I'.) Import phases $e^{i\varphi_k^{\mathcal{A}}}$ of *all* $\mathcal{A}_k$ from an ED model and fit only the $|\mathcal{A}_k|$.

Special case: electroproduction $N_{\mathcal{A}} = 6$

For electroproduction ($eN \rightarrow e'\pi N$), we have:

- $N_{\mathcal{A}} = 6$ transversity-amplitudes $b_1, \ldots, b_6$,
- phase-space kinem. variables: $\left(Q^2, W, \phi, \theta, \epsilon\right)$ $\left(\left(Q^2, W, \theta\right)\right.$ in 1-photon-approx.),
- one could use standard CGLN-expansion into *multipoles* $\left(E_{\ell\pm}, M_{\ell\pm}, L_{\ell\pm}\right)$:

$$F_1 = \sum_{\ell \geq 0} \left[(\ell M_{\ell+} + E_{\ell+}) P'_{\ell+1} + ((\ell+1) M_{\ell-} + E_{\ell-}) P'_{\ell-1} \right] ,$$

$$F_2 = \sum_{\ell \geq 1} \left[(\ell+1) M_{\ell+} + \ell M_{\ell-} \right] P'_{\ell},$$

$$F_3 = \sum_{\ell \geq 1} \left[(E_{\ell+} - M_{\ell+}) P''_{\ell+1} + (E_{\ell-} + M_{\ell-}) P''_{\ell-1} \right] ,$$

$$F_4 = \sum_{\ell \geq 2} \left[M_{\ell+} - E_{\ell+} - M_{\ell-} - E_{\ell-} \right] P''_{\ell},$$

$$F_5 = \sum_{\ell \geq 0} \left[(\ell+1) L_{\ell+} P'_{\ell+1} - \ell L_{\ell-} P'_{\ell-1} \right] ,$$

$$F_6 = \sum_{\ell \geq 1} \left[\ell L_{\ell-} - (\ell+1) L_{\ell+} \right] P'_{\ell},$$

- Take relations between F_i and b_i from e.g.: [L. Tiator, et al., Phys. Rev. C **96**, no.2, 025210 (2017)]

Advantages & disadvantages

Pros:

∗) One often obtains a very good description of the data,

∗) Penalty-term $\mathcal{P}(W)$ describes a *linear* constraint-equation for the partial-waves $\mathcal{M}_{\ell}$ (as opposed to 'quadratic' equations relating partial waves to obs.'s)
$\rightarrow$ highly constraining!

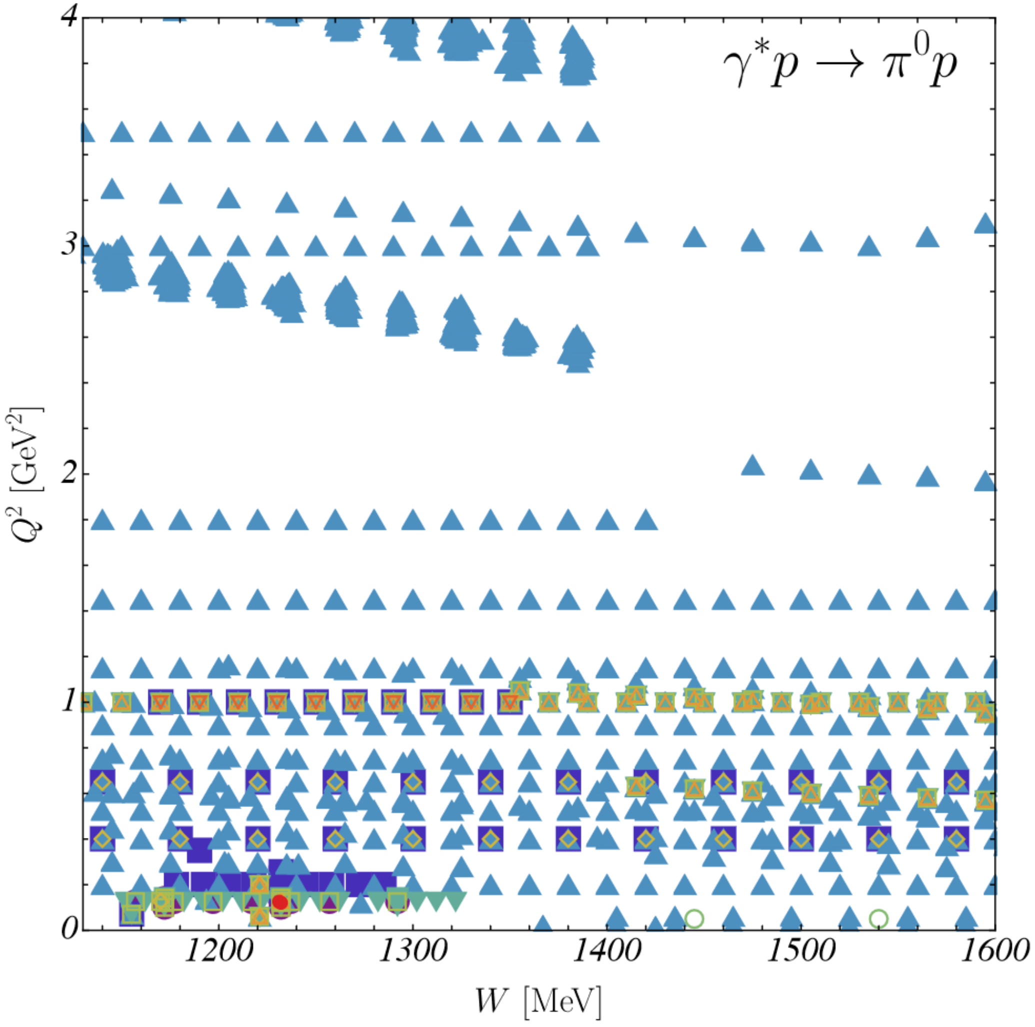
∗) In 'dream'-scenario of a perfect, complete database: overall phase $\phi(W,\theta)$ is the *only* required model-input

Cons:

∗) Kinematic binnings of observables encountered in Step I.) are often not uniform
  $\rightarrow$ Requires some 'tricks', i.e. massaging of data using interpolation-techniques or similar things, to obtain the needed uniform binning . . .

∗) Method can *never* be fully model-independent, due to undetermined overall phase (except of course one could *measure* the overall phase),

Data base in pion electroproduction



Type	N_{data}
ρ_{LT}	45
$\rho_{LT'}$	2644
σ_L	–
$d\sigma/d\Omega$	39942
$\sigma_T + \epsilon\sigma_L$	318
σ_T	10
σ_{LT}	312
$\sigma_{LT'}$	198
σ_{TT}	266
K_{D1}	1527
P_Y	2